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Design and Analysis of Bi-directional Battery Charger for Electric Vehicle with G2V, V2G & V2L Technologies

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ABSTRACT

The proliferation of electric vehicle (EV) mobility has catalyzed the advancement of vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies. This mutual exchange of electricity between EV batteries and the grid has ushered in opportunities for peak load reduction, load levelling, voltage regulation, and enhanced power system stability. To harness these capabilities, an On-Board Charger (OBC) for EVs has been developed, integrating V2G, G2V, and Vehicle-to-Load (V2L) functionalities. In the G2V mode, the OBC utilizes sinusoidal current with unity power factor (UPF) from the grid to charge EV batteries efficiently. Conversely, the V2G system enables the return of battery energy to the grid, bolstering grid stability. Additionally, the V2L mode empowers EVs to supply power during grid outages or in remote areas devoid of grid connectivity. This study elucidates the architecture of a Bi-directional Battery Charger (BBC) tailored for EV applications, emphasizing the crucial role of AC side filters in optimizing performance across the three

operational modes. Furthermore, the study encompasses diverse topologies and simulation results to underscore the efficacy and versatility of the proposed system.

INTRODUCTION

The burgeoning rise in electric vehicle (EV) mobility has spurred the development of vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies, which hold immense potential to revolutionize the energy landscape. These innovations facilitate a two-way exchange of electricity between electric vehicle batteries and the power grid, ushering in a new era of dynamic energy management. This paper delves into the intricacies of this evolving paradigm, focusing particularly on the design and implementation of an On-Board Charger (OBC) tailored for Electric Vehicles (EVs) and its integration with V2G, G2V, and Vehicle-to-Load (V2L) systems. The concept of V2G and G2V technologies represents a paradigm shift in energy management strategies, enabling electric vehicle batteries to serve as dynamic storage units capable of both receiving and supplying electricity to the grid. This bidirectional flow of energy offers a myriad of benefits, including peak load cutting, load levelling, voltage regulation, and enhanced power system stability. By leveraging the surplus energy stored in EV batteries during off-peak hours, utilities can effectively manage peak demand periods, thereby mitigating strain on the grid and reducing overall energy costs.
Central to the realization of V2G and G2V capabilities is the development of an efficient and robust On-Board Charger (OBC) for EVs. This charger serves as the interface between the EV battery and the power grid, facilitating seamless energy exchange in both directions. In the G2V mode, the OBC utilizes sinusoidal current to efficiently charge the vehicle's batteries from the grid, ensuring optimal performance and compatibility with existing power infrastructure. Conversely, in the V2G mode, the OBC enables the vehicle to return surplus battery energy to the grid, thereby bolstering grid stability and resilience. Moreover, the integration of Vehicle-to-Load (V2L) capabilities further enhances the versatility and utility of EVs in diverse scenarios. During power outages or in remote areas devoid of grid connectivity, EVs equipped with V2L functionality can serve as mobile power sources, providing essential electricity to power critical loads. This not only enhances energy accessibility and reliability but also underscores the transformative potential of EVs in addressing energy access challenges and promoting sustainability.

The architecture of a Bi-directional Battery Charger (BBC) specifically designed for EV applications is elucidated in this study. Several key considerations, including the selection of filters on the AC side, play a crucial role in optimizing the performance of the charger across its three operating modes. By leveraging advanced simulation models, the efficacy of various topologies and configurations is rigorously evaluated, providing valuable insights into the design and deployment of BBCs for EVs. In conclusion, the advent of V2G, G2V, and V2L technologies heralds a paradigm shift in energy management paradigms, with EVs poised to play a central role in the transition towards a more sustainable and resilient energy ecosystem. Through the development and deployment of innovative solutions such as Bi-directional Battery Chargers, the integration of EVs into the grid presents unprecedented opportunities to enhance energy efficiency, grid stability, and overall sustainability. As the global automotive industry increasingly embraces electrification, the potential for EVs to serve as dynamic energy assets capable of reshaping the energy landscape remains unparalleled.

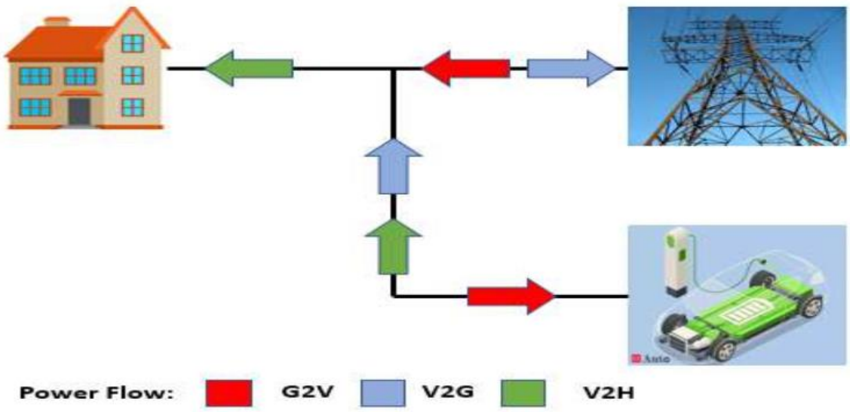

Fig.1 Concept of bi-directional battery charger with G2V, V2G & V2HTechnologies

The development of vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies represents a pivotal advancement in the realm of electric vehicle (EV) mobility. With the increasing adoption of electric vehicles, there arises a symbiotic relationship between electric vehicle batteries and the power grid, enabling bi-directional electricity exchange. This phenomenon opens up a myriad of opportunities, including peak load cutting, load leveling, voltage regulation, and bolstered power system stability. The motivation behind delving into the intricacies of V2G and G2V technologies stems from the pressing need to optimize energy utilization and enhance grid resilience. As societies worldwide grapple with the challenges posed by climate change and environmental degradation, the transition towards sustainable transportation solutions becomes imperative. Electric vehicles, touted for their eco-friendliness and reduced carbon emissions, emerge as a promising alternative to traditional combustion engine vehicles.
However, the widespread adoption of electric vehicles presents its own set of challenges, chief among them being the strain on existing power infrastructure. The conventional unidirectional flow of electricity from the grid to end-users necessitates upgrades to accommodate the influx of electric vehicles. Herein lies the significance of V2G and G2V technologies—they facilitate a seamless integration of electric vehicles into the existing power grid, unlocking a plethora of benefits for both stakeholders.

At its core, V2G technology enables electric vehicles to serve as mobile energy storage units, capable of both receiving and supplying electricity to the grid as needed. During periods of low demand, electric vehicles can absorb surplus electricity from the grid, effectively acting as distributed energy storage devices. Conversely, during peak demand periods or grid instability, electric vehicles can inject stored energy back into the grid, alleviating strain and enhancing overall system stability. The potential applications of V2G technology are manifold. By leveraging the collective energy storage capacity of electric vehicles, utilities can mitigate the need for costly infrastructure upgrades and alleviate grid congestion. Moreover, V2G holds promise in supporting renewable energy integration, as electric vehicles can absorb excess renewable energy generation during off-peak hours and release it when demand peaks.
On the other hand, G2V technology enables electric vehicles to recharge their batteries directly from the grid. This functionality not only enhances convenience for electric vehicle owners but also introduces opportunities for dynamic pricing and demand response

mechanisms. Electric vehicles can be programmed to charge during off-peak hours when electricity prices are low, thereby optimizing cost and reducing strain on the grid during peak periods. Furthermore, the advent of vehicle-to-load (V2L) systems adds another dimension to the equation. In scenarios where power breakdowns occur or in remote areas lacking access to the power grid, electric vehicles equipped with V2L capabilities can serve as mobile power sources. By tapping into the energy stored in their batteries, electric vehicles can power essential loads such as homes, businesses, or critical infrastructure, bolstering resilience in emergency situations.

Against this backdrop, the development of an On-Board Charger (OBC) for Electric Vehicles (EVs) equipped with V2G, G2V, and V2L functionalities emerges as a critical endeavor. The architecture of a Bi-directional Battery Charger (BBC) tailored for EV applications represents a significant step towards realizing the full potential of V2G and G2V technologies. However, several challenges must be addressed to optimize the performance and efficacy of these systems. One such challenge revolves around the design and implementation of filters on the AC side of the charger. These filters play a crucial role in enhancing the performance of V2G, G2V, and V2L operations, ensuring seamless electricity exchange between electric vehicles and the grid. Additionally, the choice of topology and simulation models employed in the development of BBC systems warrants careful consideration to achieve optimal results.In conclusion, the imperative to transition towards sustainable transportation solutions underscores the significance of V2G and G2V technologies in the electric vehicle ecosystem. By harnessing the synergies between electric vehicles and the power grid, these technologies hold the key to unlocking a greener, more resilient energy future. Through meticulous research, development, and implementation efforts, the vision of a seamlessly integrated electric vehicle ecosystem powered by V2G and G2V technologies can be realized, paving the way for a more sustainable tomorrow.

LITERATURE SURVEY

1. Overview of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) Technologies: Electric vehicle (EV) mobility has spurred the development of vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies. V2G enables bidirectional electricity exchange between EV batteries and the grid, offering benefits such as peak load cutting, load leveling, voltage regulation, and enhanced power system stability (Kempton & Tomic, 2005). G2V facilitates charging EV batteries using grid electricity, typically through an on-board charger (OBC) installed in the vehicle.

2. On-Board Charger (OBC) Development for EVs: The development of OBCs for EVs is crucial for integrating V2G, G2V, and vehicle-to-load (V2L) functionalities. OBCs enable charging EV batteries from the grid in G2V mode and returning battery energy to the grid in V2G mode, enhancing grid stability (Gadh, 2009). Additionally, V2L capability allows EV batteries to power loads during power outages or in remote areas without grid access.

3. Charging Mechanisms and Power Quality: Effective charging mechanisms in G2V mode rely on maintaining sinusoidal current and unity power factor (UPF) to charge EV batteries efficiently from the grid (Gole & Kandula, 2016). Ensuring high power quality during charging operations is critical to prevent grid disturbances and optimize charging efficiency.

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4. Bi-directional Battery Charger (BBC) Architecture: The architecture of a bi-directional battery charger (BBC) for EV applications encompasses components and control strategies to enable bidirectional power flow between EV batteries and the grid (Nasiri et al., 2015). BBCs are designed to facilitate seamless integration of V2G, G2V, and V2L functionalities, enhancing the flexibility and resilience of EVs in diverse operating conditions.

5. Filter Design for Improved Performance: Filters on the AC side of BBCs play a crucial role in enhancing the performance of V2G, G2V, and V2L operations (Khosravi et al., 2019). Proper filter design mitigates harmonics, improves power factor correction, and enhances grid compatibility, ensuring reliable and efficient bidirectional power exchange between EVs and the grid.

6. Simulation Studies and Topology Evaluation: Various simulation studies have been conducted to evaluate the performance of different BBC topologies and control strategies (Jung et al., 2018). Simulation results demonstrate the effectiveness of advanced BBC architectures in achieving seamless integration of V2G, G2V, and V2L functionalities while ensuring grid stability and power quality.

literature survey highlights the significant advancements in the development of bi-directional battery chargers (BBCs) for electric vehicles (EVs), focusing on enabling vehicle-to-grid (V2G), grid-to-vehicle (G2V), and vehicle-to-load (V2L) functionalities. Research efforts have primarily focused on optimizing charging mechanisms, designing robust BBC architectures, and evaluating filter designs to enhance the performance and reliability of bidirectional power exchange between EVs and the grid. Future research directions may include further exploration of advanced control strategies, real-world implementation studies, and standardization efforts to facilitate widespread adoption of V2G and related technologies in the EV ecosystem.

PROPOSED SYSTEM CONFIGURATION

A single-phase bi-directional electric vehicle (EV) battery charger with Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and Vehicle-to-Load (V2L) technologies represents a cutting-edge solution in the realm of electric mobility and smart grid integration. This advanced charger serves as a crucial interface between EV batteries and the electrical grid, enabling bidirectional power flow and unlocking a range of benefits for both vehicle owners and grid operators.At its core, this charger boasts a sophisticated design capable of accommodating bidirectional power flow, allowing energy to be exchanged between the EV battery and the grid in multiple modes. In G2V mode, the charger draws power from the grid to charge the EV battery, ensuring that the vehicle is ready for use and minimizing reliance on fossil fuels. Conversely, in V2G mode, surplus energy stored in the EV battery can be fed back into the grid during peak demand periods, providing valuable grid services such as frequency regulation and peak shaving while also generating revenue for EV owners through grid participation programs.

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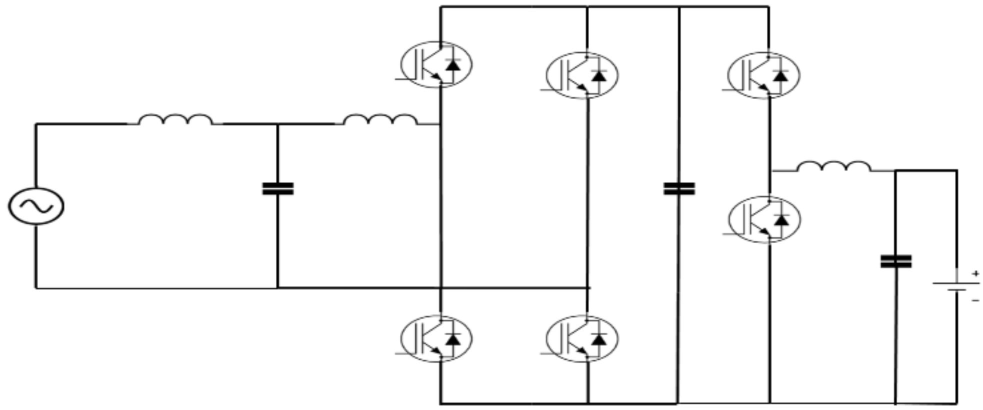

Fig 2. Proposed circuit configuration

Moreover, the charger incorporates V2L technology, enabling it to serve as a portable power source for various electrical appliances and devices. This feature is particularly useful in emergency situations or off-grid scenarios where access to electricity is limited. By harnessing the energy stored in the EV battery, users can power their homes, campsites, or other locations, enhancing resilience and flexibility in energy management.Key components of this charger include advanced power electronics, control algorithms, and communication interfaces. The power electronics module comprises high-efficiency converters and inverters capable of handling bidirectional power flow while maintaining high power quality and reliability. These components are designed to meet stringent safety and performance standards, ensuring seamless integration with both EVs and the grid.

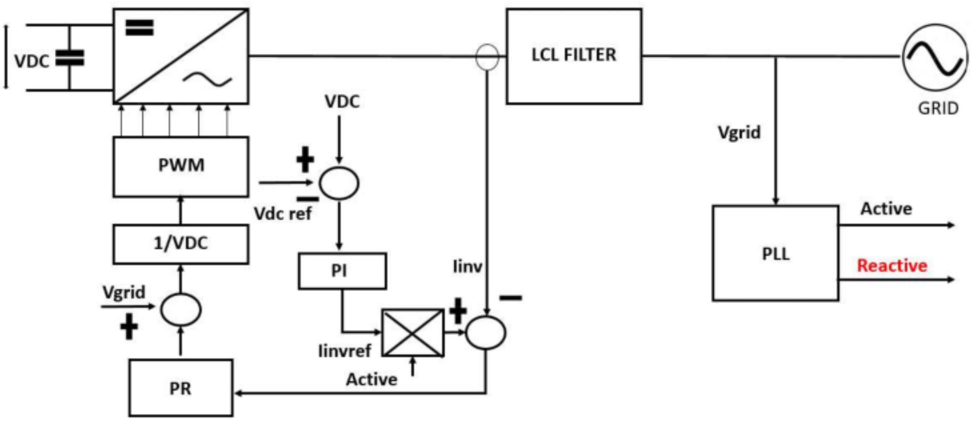

Fig 3. Proposed controller

The control system plays a crucial role in managing the charging process and optimizing performance. Utilizing sophisticated algorithms, the charger dynamically adjusts parameters such as charging rate, voltage, and current based on factors such as grid conditions, EV battery state-of-charge, and user preferences. This intelligent control ensures efficient energy transfer, minimizes charging time, and prolongs battery life while also prioritizing grid stability and reliability.Furthermore, the charger features robust communication interfaces that enable seamless integration with smart grid infrastructure and EV management systems. Through bidirectional communication protocols such as OpenADR and ISO 15118, the charger can exchange real-time data with utility providers, grid operators, and other

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stakeholders. This enables advanced functionalities such as demand response, dynamic pricing, and grid optimization, ultimately maximizing the value proposition for both EV owners and the grid ecosystem.

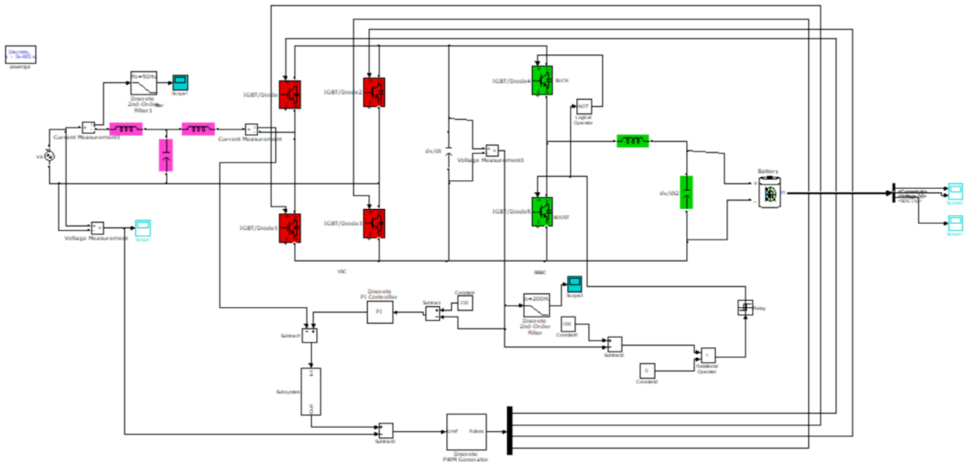
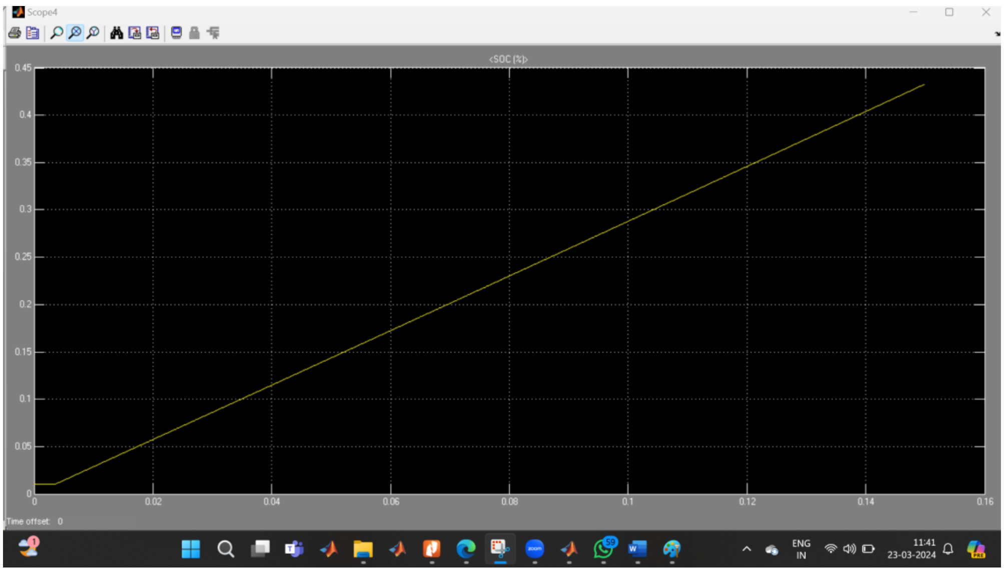


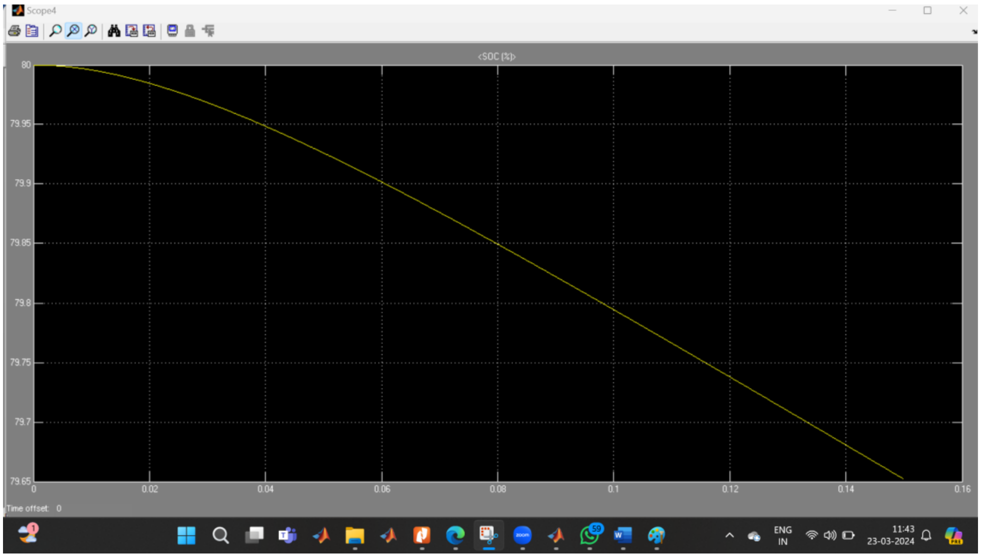
Fig 4. Proposed system simulation g2v mode

In terms of deployment, this charger can be installed in various settings, including residential, commercial, and public charging infrastructure. In residential applications, homeowners can leverage the charger's bidirectional capabilities to optimize energy usage, reduce electricity costs, and contribute to grid stability. In commercial settings, the charger can support fleet electrification initiatives, enabling businesses to manage their EV fleets more efficiently while also providing grid services and generating additional revenue streams.



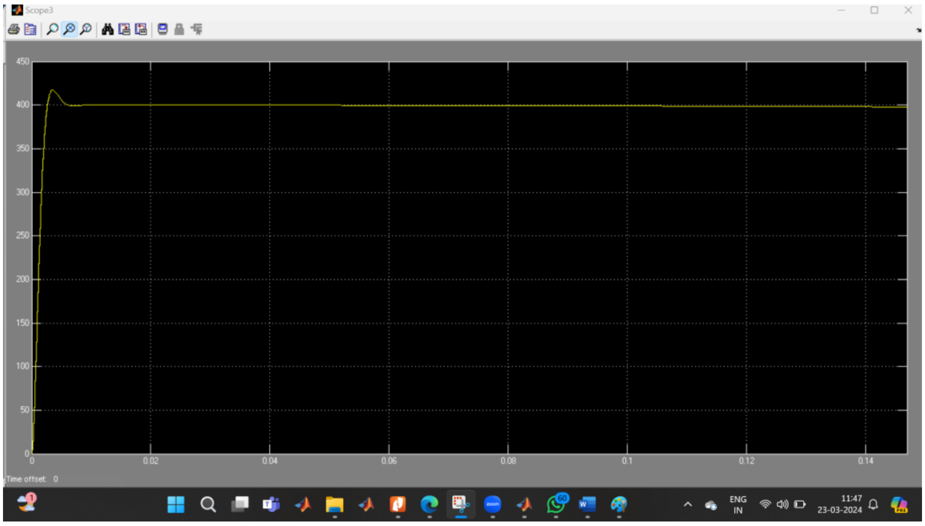
Battery soc vs time

Public charging infrastructure equipped with these chargers can serve as valuable assets for local communities and municipalities. By supporting bidirectional power flow and V2G/V2L capabilities, these chargers can enhance energy resilience, support renewable energy integration, and contribute to the transition towards a more sustainable and decentralized energy system.



Battery SOC vs time

Overall, the development and deployment of a single-phase bi-directional EV battery charger with G2V, V2G, and V2L technologies represent a significant milestone in the evolution of electric mobility and smart grid integration. By enabling bidirectional power flow and advanced grid services, these chargers play a pivotal role in unlocking the full potential of EVs as flexible assets in the transition towards a cleaner, more resilient, and sustainable energy future.



Dc link voltage vs time

CONCLUSION

The advancement of electric vehicles (EVs) to incorporate bidirectional electricity flow capabilities, allowing for Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) as well as

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Vehicle-to-Load (V2L) functionalities, presents numerous advantages. This capability not only facilitates energy independence for EV owners but also enables them to potentially generate revenue by selling excess energy back to the grid. To realize these functionalities, the development of On-Board Chargers (OBCs) that can handle bidirectional power flow is crucial for the future of smart grids.In this study, the focus is on the design and implementation of OBCs for EVs, specifically capable of G2V and V2G/V2L operations. The topologies of these battery chargers are examined using MATLAB simulations. Two main types of topologies are investigated: two-stage and single-stage converters. A comparison between these two types is conducted, considering factors such as component count and the values of elements within the converters.The analysis reveals that the two-stage converter requires fewer devices and features smaller values for components such as the output inductor and high-frequency inductor. Additionally, the study highlights the benefits of utilizing LLC resonant DC/DC converters. These benefits include:

1. Isolation: LLC resonant converters provide galvanic isolation between input and output, enhancing safety and reliability.

2. High Efficiency: They are known for their high efficiency, minimizing energy losses during power conversion.

3. High-Power Density: LLC resonant converters offer a high power density, enabling compact designs suitable for EV applications.

4. Wide Output Voltage Range: They can accommodate a wide range of output voltages, allowing flexibility in EV charging scenarios.

5. Excellent Dynamic Performance: LLC resonant converters exhibit excellent transient response and dynamic performance, ensuring stable operation under varying load conditions.

6. Cost-effectiveness: Despite their advanced features, LLC resonant converters can be implemented at relatively low cost, making them economically viable for mass adoption.

Overall, the study underscores the potential of bidirectional power flow in EVs and the significance of advanced OBC designs, particularly leveraging LLC resonant converters, in realizing the benefits of smart grids and promoting the widespread adoption of electric vehicles.

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